APPENDIX C

Minimum Standards for Slope Stability Analyses

Sensitive Lands Evaluation & Development Standards (SLEDS)
Chapter 19.72, COTTONWOOD HEIGHTS CODE OF ORDINANCES

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1.0 INTRODUCTION

The procedures outlined in this appendix are intended to provide consultants with a general outline for performing quantitative slope stability analyses and to clarify the expectations of the city of Cottonwood Heights (the "*city*"). These standards constitute the minimum level of effort required in conducting quantitative slope stability analyses in the city. Considering the complexity inherent in performing slope stability analyses, additional effort beyond the minimum standards presented herein may be required at some sites to adequately address slope stability. The information presented herein does not relieve consultants of their duty to perform additional geologic or engineering analyses they believe are necessary to assess the stability of slopes at a site.

The evaluation of landslides generally requires quantitative slope stability analyses. Therefore, the standards presented herein are directly applicable to landslide investigation, and also constitute the *minimum* level of effort when performing landslide investigations. This appendix does not address debris flows (*see* Appendix E) or rock falls (*see* Appendix F).

1.1 ***Purposes*.** The purposes for establishing minimum standards for slope stability analyses are to:

(a) Protect the health, safety, welfare, and property of the public by minimizing the potentially adverse effects of unstable slopes and related hazards;

(b) Assist property owners and land developers in conducting reasonable and adequate slope stability studies;

(c) Provide consulting engineering geologists and geotechnical engineers with a common basis for preparing proposals, conducting investigations, and designing and implementing mitigation; and

(d) Provide an objective framework for regulatory review of slope stability reports.

1.2 ***References and Sources.*** The minimum standards presented in this appendix were developed, in part, from the following sources:

(a) Guidelines for Evaluating Landslide Hazards in Utah (Hylland, 1996).

(b) Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Landslide Hazards in California (Blake et al., 2002).

(c) CDMG Special Publication 117, Guidelines for Analyzing and Mitigating Landslide Hazards in California.

(d) Salt Lake County Geologic Hazards Ordinance (2002).

(e) Cottonwood Heights, Utah Code of Ordinances (2005).

(f) City of Draper, Utah, Title 9, Land Use and Development Code for Draper City, Chapter 9-19, Geologic Hazards Ordinance, December 11, 2007.

1.3 ***Areas Requiring Slope Stability Analyses.***

(a) Slope stability analyses shall be performed for all sites located within the Slope Stability Study Area Map and for all slopes that may be affected by the proposed development which meet the following criteria:

(i) Cut and/or fill slopes steeper than about 2 horizontal (h) to 1 vertical (v).

(ii) Natural slopes steeper than or equal to 3 horizontal (h) to 1 vertical (v).

(iii) Natural and cut slopes with potentially adverse geologic conditions (e.g. bedding, foliation, or other structural features that are potentially adverse to the stability of the slope).

(iv) Natural and cut slopes which include a geologic hazard such as a landslide, irrespective of the slope height or slope gradient.

(v) Buttresses and stability fills.

(vi) Cut, fill, or natural slopes of water-retention basins or flood-control channels.

(b) In hillside areas, investigations shall address the potential for surficial instability, debris/mudflows (see Appendix E), rock falls (see Appendix F), and soil creep on all slopes that may affect the proposed development or be affected by the proposed development.

(c) When evaluating site conditions to determine the need for slope stability analyses, off-property conditions shall be considered (both up-slope to the top(s) of adjacent ascending slopes and down-slope to and beyond the toe(s) of adjacent descending slopes). Also, the consultant shall demonstrate that the proposed hillside development will not affect adjacent sites or limit adjacent property owners' ability to develop their sites.

1.4 ***Roles of Engineering Geologist and Engineering.***

The investigation of the static and seismic stability of slopes is an interdisciplinary practice. To provide greater assurance that the hazards are properly identified, assessed, and mitigated, involvement of both an engineering geologist and geotechnical engineer is required. Analyses shall be performed only by or under the direct supervision of licensed professionals, qualified and competent in their respective area of practice. An engineering geologist shall provide appropriate input to the geotechnical engineer with respect to the potential impact of the geology, stratigraphy, and hydrologic conditions on the stability of the slope. The shear strength and other geotechnical earth material properties shall be evaluated by the geotechnical engineer. All slope stability should be performed by a qualified and licensed engineer or under the purview of a licensed engineer. Ground motion parameters for use in seismic stability analysis may be provided by either the engineering geologist or geotechnical engineer.

2.0 GENERAL REQUIREMENTS

Except for the derivation of the input ground motion for pseudostatic and seismic deformation analyses (see Section 12), slope stability analyses and evaluations should be performed in general accordance with the latest version of Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Landslide Hazards in California (Blake et al., 2002). Procedures for developing input ground motions to be used in the city are described in Section 12.1.

3.0 SUBMITTALS

(a) Submittals for review shall include boring logs; geologic cross sections; trench and test pit logs; laboratory data (particularly shear strength test results, including individual stress-deformation plots from direct shear tests); discussions pertaining to how idealized subsurface conditions and shear strength parameters used for analyses were developed; analytical results, and summaries of the slope stability analyses and conclusions regarding slope stability.

(b) Subsurface geologic and groundwater conditions must be illustrated on geologic cross sections and must be utilized by the geotechnical engineer for the slope stability analyses. If on-site sewage or storm water disposal exists or is proposed, the slope stability analyses shall include the effects of the effluent plume on slope stability.

(c) The results of any slope stability analyses must be submitted with pertinent backup documentation (i.e., calculations, computer output, etc.). Printouts of input data, output data (if requested), and graphical plots must be submitted for each computer-aided slope stability analysis.

4.0 FACTORS OF SAFETY

The minimum acceptable static factor of safety is 1.5 for both gross and surficial slope stability. The minimum acceptable factor of safety for a *calibrated pseudostatic analysis* is 1.0 using the method of Stewart et al. (2003) (see Section 12.2).

5.0 LANDSLIDES

The evaluation of landslides generally requires quantitative slope stability analyses. Therefore, the standards presented herein are directly applicable to landslide investigation, and also constitute the minimum level of effort when performing landslide investigations. Evaluation of landslides shall be performed in the preliminary phase of hillside developments. Where landslides are present or suspected, sufficient subsurface exploration will be required to determine the basic geometry and stability of the landslide mass and the required stabilization measures. The depth of geologic exploration shall consider the regional geologic structure, the likely failure mode of the suspected failure, and past geomorphic conditions.

6.0 SITE INVESTIGATION AND GEOLOGIC STUDIES

(a) Adequate evaluation of slope stability for a given site requires thorough and comprehensive geologic and geotechnical engineering studies. These studies are a crucial component in the evaluation of slope stability. Geologic mapping and subsurface exploration are normal parts of field investigation. Samples of earth materials are routinely obtained during subsurface exploration for geotechnical testing in the laboratory to determine the shear strength parameters and other pertinent engineering properties.

(b) In general, geologic studies for slope stability consist of the following fundamental phases:

(i) Study and review of published and unpublished geologic information (both regional and site specific).

(ii) Review and interpretation of available stereoscopic and oblique aerial photographs, DEMs, and LiDAR data.

(iii) Geologic field mapping, including, but not necessarily limited to, measurement of bedding, foliation, fracture, and fault attitudes and other parameters.

(iv) Documentation and evaluation of subsurface groundwater conditions (including effects of seasonal and longer-term natural fluctuations as well as landscape irrigation), surface water, on-site sewage disposal, and/or storm water disposal.

(v) Subsurface exploration.

(vi) Analysis of the geologic failure mechanisms that could occur at the site (e.g., mode of failure and construction of the critical geologic cross sections).

(vii) Presentation and analysis of the data, including an evaluation of the potential impact of geologic conditions on the project.

(c) Geologic/geotechnical reports shall demonstrate that each of the phases described in subsection 6.0(b) has been adequately performed and that the information obtained has been considered and logically evaluated. Minimum criteria for the performance of each phase are described and discussed in Blake et al. (2002).

7.0 SUBSURFACE EXPLORATION

The purpose of subsurface exploration is to identify potentially significant geologic materials and structures at a site and to provide samples for detailed laboratory characterization of materials from potentially critical zones. Subsurface exploration is almost always required and may be performed by a number of widely known techniques such as bucket-auger borings, conventional small-diameter borings, cone penetration testing (CPT), test pits, trenches, and/or geophysical techniques (see section 4.2 of Blake et al., 2002). In general, subsurface explorations should extend to a minimum depth of the anticipated failure planes or 2/3 the maximum height of the slope, whichever is greater. A discussion of the applicability of some subsurface exploration techniques follows.

7.1 *Trenching*. Subsurface exploration consisting of trenching has proven, in some cases, to be necessary when uncertainty exists regarding whether or not a particular landform is a landslide. Care must be exercised with this exploration method because landslides characteristically contain relatively large blocks of intact geologic units, which in a trench exposure could give the false impression that the geologic unit is “in-place.” Although limited to a depth of about 15 feet below existing grades, trenching has also proven to be a useful technique for verifying margins of landslides, although the geometry of a landslide can generally be readily determined from evaluation of stereoscopic aerial photographs. Once a landslide is identified, conventional subsurface exploration drilling techniques will be required (see Section 7.2 and 7.3). Slope stability analyses based solely on data obtained from trenches will not be accepted.

7.2 _Methods for Bedded Formations_.

(a) Conventional subsurface exploration techniques involving continuous core drilling with an oriented core barrel, test pits, and deep bucket-auger borings may be used to assess the subsurface soil and geologic conditions, particularly for geologic units with inclined bedding that includes weak layers.

(b) Particular attention must be paid to the presence or absence of weak layers (e.g.., clay, claystone, silt, shale, or siltstone units) during the exploration. Unless adequately demonstrated (through comprehensive and detailed subsurface exploration) that weak (clay, claystone, silt, shale, or siltstone) layers (even as thin as 1/16-inch or less) are not present, a weak layer shall be assumed to possibly occur anywhere in the stratigraphic profile (i.e., ubiquitous weak clay beds).

(c) The depth of the subsurface exploration must be sufficient to assess the conditions at or below the level of the deepest potential failure surface possessing a factor of 1.5 or less. A preliminary slope stability analysis may need to be performed to assist in the planning of the subsurface exploration program.

7.3 _Other Geologic Units_. For alluvium, fill materials, or other soil units that do not contain weak interbeds, other exploration methods such as small-diameter borings (e.g., rotary wash or hollow-stem-auger) or cone penetration testing may be suitable.

8.0 SOIL PARAMETERS

Soil properties, including unit weight and shear strength parameters (cohesion and friction angle), may be based on conventional field and laboratory tests as well as on field performance. Where appropriate (i.e., for landslide slip surfaces, along bedding planes, for surficial stability analyses, etc.), laboratory tests for saturated, residual shear strengths must be performed. Estimation of the shear resistance along bedding (or landslide) planes normally requires an evaluation of saturated residual along-bedding-strength values of the weakest interbedded (or slide-plane) material encountered during the subsurface exploration, or in the absence of sufficient exploration, the weakest material that may be present, consistent with site geologic conditions. Strength parameters derived solely from CPT data may not be appropriate for slope-stability analysis in some cases, particularly for strengths along existing slip surfaces where residual strengths have developed. Additional guidance on the selection of strength parameters for slope stability analyses is contained in Blake et al. (2002).

8.1 _Residual Shear Strength Parameters_. Residual strength parameters may be determined using the direct shear or ring shear testing apparatus; however, ring shear tests are preferred. If performed properly, direct shear test results may approach ring-shear test results. The soil specimen must be subjected to a sufficient amount of deformation (e.g., a significant number of shearing cycles in the direct shear test or a significant amount of rotation in the ring shear test) to assure that residual strength has been developed. In the direct-shear and ring-shear tests, stress-deformation curves can be used to determine when a sufficient number of cycles of shearing have been performed by showing that no further significant drop in shear strength results with the addition of more cycles or more rotation. The stress-deformation curves obtained during the shear tests must be submitted with the other laboratory test results. It shall be recognized that for most clayey soils, the residual shear strength envelope is curved and passes through the origin (i.e., at zero normal stress there is zero shear strength). Any “apparent shear strength” increases resulting from a non-horizontal shear surface (i.e., ramping) or “bulldozing” in residual direct shear tests shall be discounted in the interpretation of the strength parameters.

8.2 ***Interpretation*.**

(a) The engineer will need to use considerable judgment in the selection of appropriate shear test methods and in the interpretation of the results to develop shear strength parameters commensurate with slope stability conditions to be evaluated. Scatter plots of shear strength data may need to be presented to allow for assessment of idealized parameters. The report shall summarize shear strength parameters used for slope stability analyses and describe the methodology used to interpret test results and estimate those parameters.

(b) Peak shear strengths may be used to represent across-bedding failure surfaces or compacted fill, in situations where strength degradations are not expected to occur (see guidelines in Blake et al., 2002). Where peak strengths cannot be relied upon, fully softened (or lower) strengths shall be used.

(c) Ultimate shear strength parameters shall be used in static slope stability analyses when there has *not* been past deformation. Residual shear strength parameters shall be used in static slope stability analyses when there has been past deformation.

(d) Averaged strength parameters may be appropriate for some across-bedding conditions, if sufficient representative samples have been carefully tested. Analyses for along-bedding or along-existing-landslide slip surfaces shall be based on lower-bound interpretations of residual shear strength parameters and comparison of those results to correlations, such as those of Stark et al. (2005).

9.0 SOIL CREEP

(a) The potential effects of soil creep shall be addressed where any proposed structure is planned in close proximity to an existing fill slope or natural slope. The potential effects on the proposed development shall be evaluated and mitigation measures proposed, including appropriate setback recommendations. Setback recommendations shall consider the potential affects of creep forces.

(b) All reports in hillside areas shall address the potential for surficial instability, debris/mudflow (Appendix E), rock falls (Appendix F), and soil creep on all slopes that may affect the proposed development or be affected by the proposed development. Stability of slopes along access roads shall be addressed.

10.0 GROSS STATIC STABILITY

Gross stability includes rotational and translational deep-seated failures of slopes or portions of slopes existing within or outside of but potentially affecting the proposed development. The following guidelines, in addition to those in Blake et al. (2002), shall be followed when evaluating slope stability:

(a) Stability shall be analyzed along cross sections depicting the most adverse conditions (e.g., highest slope, most adverse bedding planes, shallowest likely ground water table, and steepest slope). Often analyses are required for different conditions and for more than one cross section to demonstrate which condition is most adverse. When evaluating the stability of an existing landslide, analyses must also address the potential for partial reactivation. Inclinometers may be used to help determine critical failure surfaces and, along with high-resolution GPS, the state of activity of existing landslides. The critical failure surfaces on each cross-section shall be identified, evaluated, and plotted on the large-scale cross section.

(b) If the long-term, static factor of safety is less than 1.5, mitigation measures will be required to bring the factor of safety up to the required level or the project may be redesigned to achieve a minimum factor of safety of 1.5.

(c) The temporary stability of excavations shall be evaluated and mitigation measures shall be recommended as necessary to obtain a minimum factor of safety of 1.3.

(d) Long-term stability shall be analyzed using the highest known or anticipated groundwater level based upon a groundwater assessment performed under the requirements of Section 6.0.

(e) Where back-calculation is appropriate, shear strengths utilized for design shall be no higher than the lowest strength computed using back calculation. If a consultant proposes to use shear strengths higher than the lowest back-calculated value, justification shall be required. Assumptions used in back-calculations regarding pre-sliding topography and groundwater conditions at failure must be discussed and justified.

(f) Reports shall describe how the shear strength testing methods used are appropriate in modeling field conditions and long-term performance of the subject slope. The utilized design shear strength values shall be justified with laboratory test data and geologic descriptions and history, along with past performance history, if known, of similar materials.

(g) Reports shall include shear strength test plots consisting of normal stress versus shear resistance (failure envelope). Plots of shear resistance versus displacement shall be provided for all residual and fully softened (ultimate) shear tests.

(h) The degree of saturation for all test specimens shall be reported. Direct shear tests on partially saturated samples may grossly overestimate the cohesion that can be mobilized when the material becomes saturated in the field. This potential shall be considered when selecting shear strength parameters. If the rate of shear displacement exceeds 0.005 inches per minute, the consultant shall provide data to demonstrate that the rate is sufficiently slow for drained conditions.

(i) Shear strength values higher than those obtained through site-specific laboratory tests generally will not be accepted.

(j) If direct shear or triaxial shear testing is not appropriate to model the strength of highly jointed and fractured rock masses, the design strengths shall be evaluated in a manner that considers overall rock mass quality and be consistent with rock mechanics practice.

(k) Shear strengths used in slope stability analyses shall be evaluated considering the natural variability of engineering characteristics inherent in earth materials. Multiple shear tests on each site material will typically to be required.

(l) Direct shear tests do not always provide realistic strength values (Watry and Lade, 2000). Correlations between liquid limit, percent clay fraction, and strength (fully softened and residual) with published data (e.g., Stark and McCone, 2002) shall be performed to verify tested shear strength parameters. Strength values used in analyses that exceed those obtained by the correlation must be appropriately justified.

(m) Shear strengths for proposed fill slopes shall be evaluated using samples mixed and remolded to represent anticipated field conditions. Confirming strength testing may be required during grading.

(n) Where bedding planes are laterally unsupported on slopes, potential failures along the unsupported bedding planes shall be analyzed. Similarly, stability analyses shall be performed where bedding planes form a dip-slope or near-dip-slope using composite potential failure surfaces that consist of potential slip surfaces along bedding planes in the upper portions of the slope in combination with slip surfaces across bedding planes in the lower portions of the slope.

(o) The stability analysis shall include the effect of expected maximum moisture conditions on soil unit weight.

(p) For effective stress analyses, measured groundwater conditions adjusted to consider likely unfavorable conditions with respect to anticipated future groundwater levels, seepage, or pore pressure shall be included in the slope stability analyses.

(q) Tension crack development shall be considered in the analyses of potential failure surfaces. The height and location of the tension crack shall be determined by searching.

(r) Anticipated surcharge loads as well as external boundary pressures from water shall be included in the slope stability evaluations, as deemed appropriate.

(s) Analytical chart solutions may be used provided they were developed for conditions similar to those being analyzed. Generally though, computer-aided searching techniques shall be used, so that the potential failure surface with the lowest factor of safety can be located. Examples of typical searching techniques are illustrated on figures 9.1(a) through 9.1(f) in Blake et al. (2002). However, verification of the reasonableness of the analytical results is the responsibility of the geotechnical engineer and/or engineering geologist.

(t) The critical potential failure surface used in the analysis may be composed of circles, wedges, planes, or other shapes considered designed to yield the minimum factor of safety most appropriate for the geologic site conditions. The critical potential failure surface having the lowest factor of safety with respect to shearing resistance must be sought. Both the lowest factor of safety and the critical failure surface shall be documented.

11.0 SURFICIAL STABILITY OF SLOPES

Surficial slope stability refers to slumping and sliding of near-surface sediments and is most critical during the snowmelt and rainy season or when excessive landscape water is applied. The assessment of surficial slope stability shall be based on analysis procedures for stability of an infinite slope with seepage parallel to the slope surface or an alternate failure mode that would produce the minimum factor of safety. The minimum acceptable depth of saturation for surficial stability evaluation shall be four feet.

11.1 ***Applicability and Procedures*.**

(a) Conclusions shall be substantiated with appropriate data and analyses. Residual shear strengths comparable to actual field conditions shall be used in completing surficial stability analyses. Surficial stability analyses shall be performed under rapid draw-down conditions where appropriate (e.g., for debris and detention basins).

(b) Where 2:1 or steeper slopes have soil conditions that can result in the development of an infinite slope with parallel seepage, calculations shall be performed to demonstrate that the slope has a minimum static factor of safety of 1.5, assuming a fully saturated 4-foot thickness. If conditions will not allow the development of a slope with parallel seepage, surficial slope stability analyses may not be required (provided the geologic/geotechnical reviewer concurs).

(c) Surficial slope stability analyses shall be performed for fill, cut, and natural slopes assuming an infinite slope with seepage parallel to the slope surface or other failure mode that would yield the minimum factor of safety against failure. A suggested procedure for evaluating surficial slope stability is presented in Blake et al. (2002).

11.2 *Soil Properties*. Soil properties used in surficial stability analyses shall be determined as noted in Section 8.1. For sites with deep slip surfaces, the guidelines given by Blake et al. (2002) should be followed.

11.3 *Seepage Conditions*. The minimum acceptable vertical depth for which seepage is parallel to the slope shall be applied is four feet for cut or fill slopes. Greater depths may be necessary when analyzing natural slopes that have significant thicknesses of loose surficial material.

12.0 SEISMIC SLOPE STABILITY

In addition to static slope stability analyses, slopes shall be evaluated for seismic slope stability as well. Acceptable methods for evaluating seismic slope stability using calibrated pseudo-static limit-equilibrium procedures and simplified methods (e.g., those based on Newmark, 1965) to estimate permanent seismic slope movements are summarized in Blake et al. (2002). Nonlinear, dynamic finite element/finite difference numerical methods also may be used to evaluate slope movements resulting from seismic events as long as the procedures, input data, and results are thoroughly documented, and deemed acceptable by the city.

12.1 *Ground Motion for Pseudostatic and Seismic Deformation Analyses*.

(a) The controlling fault that would most affect the city is the Salt Lake City segment of the Wasatch fault zone (WFZ). Repeated Holocene movement has been well documented along this segment (Black et al., 2003). Studies along the Salt Lake City segment of the WFZ indicate a recurrence interval of about 1,300 years and the most recent event being about 1,300 years ago (Lund, 2005). Based on the paleoseismic record of the Salt Lake City segment and assuming a time-dependent model, McCalpin (2002) estimates a conditional probability (using a log-normal renewal model) of 16.5% in the next 100 years (8.25% in the next 50 years) for a M>7 surface-faulting earthquake. Therefore, using a time-dependent rather than Poisson or random model for earthquake recurrence, the likelihood of a large surface-faulting earthquake on the Salt Lake City segment of the WFZ is relatively high and therefore the Salt Lake City segment is considered the primary controlling fault for deterministic analyses.

(b) Regarding design ground accelerations for seismic slope-stability analyses, the city prefers a probabilistic approach to determining the likelihood that different levels of ground motion will be exceeded at a particular site within a given time period. In order to more closely represent the seismic characteristics of the WFZ and better capture this possible high likelihood of a surface-faulting earthquake on the Salt Lake City segment, design ground motion parameters for seismic slope stability analyses shall be based on the peak accelerations with a 2.0 percent probability in 50 years (2,500-year return period). Peak bedrock ground motions can be readily obtained via the internet from the United States Geological Survey (USGS) National Seismic Hazard Maps, Data and Documentation web page (USGS, 2002), which is based on Frankel et al., 2002. PGAs obtained from the USGS (2002) web page should be adjusted for effects of soil/rock (site-class) conditions in accordance with Seed et al. (2001). Site specific response analysis may also be used to develop PGA values as long as the procedures, input data, and results are thoroughly documented, and deemed acceptable by the city.

12.2 *Pseudo-Static Evaluations*.

(a) Pseudo-static methods for evaluating seismic slope stability are acceptable as long as minimum factors of safety are satisfied, and appropriate consideration is given in the selection of the seismic coefficient, kh, reduction in material shear strengths, and the factor of safety for pseudo-static conditions.

(b) Pseudo-static seismic slope stability analyses can be performed using the "screening analysis" procedure described in Blake et al. (2002). For that procedure a kh-value is selected from seismic source characteristics (modal magnitude, modal distance, and firm rock peak ground acceleration) and an acceptable level of deformation is specified. For this procedure, a factor of safety of 1.0 or greater is considered acceptable; otherwise, an analysis of permanent seismic slope deformation shall be performed.

12.3 *Permanent Seismic Slope Deformation*.

(a) For seismic slope stability analyses, estimates of permanent seismic displacement are preferred and may be performed using the procedures outlined in Blake et al. (2002). It should be noted that Bray and Rathje (1998), referenced in Blake et al. (2002), has been updated and superseded by Bray and Travasarou (2007), which is the city's currently preferred method. For these analyses, calculated seismic displacements shall be 15 cm or less, or mitigation measures shall be proposed to limit calculated displacements to 15 cm or less.

(b) For specific projects, different levels of tolerable displacement may be possible, but site-specific conditions, which shall include the following, must be considered:

(i) The extent to which the displacements are localized or broadly distributed – broadly distributed shear deformations would generally be less damaging and more displacement could be allowed.

(ii) The displacement tolerance of the foundation system – stiff, well-reinforced foundations with lateral continuity of vertical support elements would be more resistant to damage (and hence could potentially tolerate larger displacements) than typical slabs-on-grade or foundation systems with individual spread footings.

(iii)The potential of the foundation soils to experience strain softening – slopes composed of soils likely to experience strain softening should be designed for relatively low displacements if peak strengths are used in the evaluation of k_y due to the potential for progressive failure, which could involve very large displacements following strain softening.

(c) In order to consider a threshold larger than 15 cm, the project consultant shall provide prior, acceptable justification to the city and obtain the city's approval. Such justification shall demonstrate, to the city's satisfaction, that the proposed project will achieve acceptable performance.

13.0 WATER RETENTION BASINS AND FLOOD CONTROL CHANNELS

For cut, fill, or natural slopes of water-retention basins or flood-control channels, slope stability analyses shall be performed. In addition to analyzing typical static and seismic slope stability, those analyses shall consider the effects of rapid drawdown, if such a condition could develop. All proposed structures should be permitted under Utah Dam Safety rules, as applicable.

14.0 MITIGATION

(a) When slope stability hazards are determined to exist on a project, measures to mitigate impacts from those hazards shall be implemented. Some guidance regarding mitigation measures is provided in Blake et al. (2002). Slope stability mitigation methods include:

(i) hazard avoidance,
(ii) grading to improve slope stability,
(iii)reinforcement of the slope or improvement of the soil within the slope, and
(iv)reinforcement of the structure built on the slope to tolerate anticipated slope displacements.

(b) Where mitigation measures that are intended to add stabilizing forces to the slope are to be implemented, consideration should be given to strain compatibility.

14.1 ***Full Mitigation*****.** Full mitigation of slope stability hazards shall be performed for developments in the city. Remedial measures that produce static factors of safety in excess of 1.5 and acceptable seismic displacement estimates shall be implemented as needed.

14.2 ***Partial Mitigation for Seismic Displacement Hazards*****.** On some projects, or portions thereof (such as small structural additions, residential "infill projects", non-habitable structures, and non-structural natural-slope areas), full mitigation of seismic slope displacements may not be possible, due to physical or economic constraints. In those cases, partial mitigation, to the extent that it prevents structural collapse, injury, and loss of life, may be possible if it can be provided consistent with IBC philosophies, and if it is approved by the city. The applicability of partial mitigations to specific projects will be evaluated on a case-by-case basis.

15.0 NOTICE OF GEOLOGIC HAZARD AND WAIVER OF LIABILITY.

For developments where full mitigation of seismic slope displacements is not implemented, a Notice of Geologic Hazard shall be recorded with the proposed development describing the displacement hazard at issue and the partial mitigation employed. The Notice shall clearly state that the seismic displacement hazard at the site has been reduced by the partial mitigation, but not totally eliminated. The Notice also shall provide that the owner assumes all risks, waives all claims against the city and its consultants, and indemnifies and holds the city and its consultants harmless from any and all claims arising from the partial mitigation of the seismic displacement hazard.

APPENDIX C - REFERENCES

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